

ICANS I

Notes on the First Meeting of
the International Collaboration
on Advanced Neutron Sources

Held at Argonne National Laboratory
Compiled at Rutherford Laboratory

Report on the Workshop on Accelerators
and Targets for Pulsed Spallation Neutron Sources
Held as Part of the
International Collaboration on Advanced Neutron Sources

The first major meeting of the parties involved in the International Collaboration on Advanced Neutron Sources (ICANS) was held at Argonne National Laboratory December 12-15, 1977. Personnel from the Argonne National Laboratory (USA), Los - Alamos Scientific Laboratory (USA), and the Rutherford Laboratory (GB) participated in discussions under the general topical heading "Workshop on Accelerators and Targets for Pulsed Spallation Neutron Sources." The meeting agenda is given below.

International Collaboration on Advanced
Neutron Sources

Workshop on Accelerators and Targets
for Pulsed Spallation Neutron Sources

Argonne National Laboratory
12-15 December, 1977

AGENDA

Sunday, December 11, 1977

7:00 p.m. Informal Reception*

Monday, December 12, 1977

Plenary Session*

9:00 a.m. Welcoming Address
R. G. Sachs

9:10 Review of the Intense Pulsed Neutron Source
J. M. Carpenter, Program Director, Intense Pulsed
Neutron Source

9:30 Review Cost and Time Schedule for the IPNS
Construction Project
N. J. Swanson, Project Manager, Intense Pulsed Neutron Source

10:10 Review of the High Intensity Synchrotron
 J. D. Simpson, Accelerator Facilities Project
 Manager, Intense Pulsed Neutron Source

10:30 Coffee

 Plenary Session

11:00 Review of Booster II
 J. D. Simpson, Accelerator Facilities Project
 Manager, Intense Pulsed Neutron Source

11:20 Review of IPNS Target Design
 B. Johnson, ARACOR Corporation

12:00 Review of LASL Storage Ring
 Richard K. Cooper, LASL

 Lunch,

 Plenary Session,

1:30 Review of SNS Design
 Grahame Rees, Rutherford Laboratory

2:30 Instructions to the Workshop
 J. M. Carpenter, J. D. Simpson

3:00 Tour of Booster II, ZING-P', IPNS Area, start in
 Main Control Room

4:30 Informal Discussions
 Conference Room , Building 360

6:00 Social Hour and Dinner*

Workshops

Tuesday, December 13, 1977 and Wednesday, December 14, 1977, all day

Accelerator Problems

Chopper-Ring Synchronization
 Extraction
 H⁻ Sources
 Injection
 Linac Losses and Activation Problems
 Magnet Power Supplies
 Magnets and Vacuum Vessel
 Reconciliation of SNS and HIS Space Charge Limits
 Strippers
 Synchrotron Instabilities
 Synchrotron Losses and Activation Problems

Targets, Moderators, Calculations, Codes, InstrumentsThursday, December 15, 1977

9:00 a.m.	Informal Discussion
10:00	Summaries of workshop group discussion by designated persons.
12:30	<u>Lunch</u>
1:30	Discussion of Needed Actions, Review Draft Agenda for 2nd ICANS Meeting July 10-15, at Rutherford Preliminary discussion of Topic for 3rd ICANS Meeting, (February, 1979) (LASL)
3:00	Adjournment

*Several functions of this workshop are combined with those which are simultaneously a part of the IPNS Proposal Review Meeting.

SUMMARY OF DISCUSSIONS

Although the meeting was called a workshop, the general consensus was that it might better have been called an information exchange since the various discussion sessions were devoted almost exclusively to this purpose. Nevertheless it was felt by all that this was a very useful function. The informal discussions in the various subject areas are summarized below.

A. Accelerator ProblemsParticipants

R. Bennett	Rutherford Laboratory
J. Bywater	Argonne National Laboratory
R. Cooper	Los Alamos Scientific Laboratory

E. Crosbie	Argonne National Laboratory
J. Fasolo	Argonne National Laboratory
M. Foss	Argonne National Laboratory
T. Hardek	Argonne National Laboratory
H. R. Hiddleston	Argonne National Laboratory
T. Khoe	Argonne National Laboratory
G. Ostrowski	Argonne National Laboratory
C. Pelizzari	Argonne National Laboratory
C. Potts	Argonne National Laboratory
W. Praeg	Argonne National Laboratory
L. Ratner	Argonne National Laboratory
G. Rees	Rutherford Laboratory
J. Simpson	Argonne National Laboratory
D. Suddeth	Argonne National Laboratory
K. Thompson	Argonne National Laboratory
B. Ward	Rutherford Laboratory
N. West	Rutherford Laboratory

A.1 Ion Sources

The two types of ion sources potentially capable of providing the beam intensity and duty cycle required for pulsed spallation neutron sources have been studied and evaluated. During the last year or so, significant advances have occurred in the development of direct-extraction surface-plasma H^- ion sources. Existing Penning-discharge versions of the surface-plasma source at Novosibirsk, where this type of source originated, at BNL, where it has been under development for several years, at LASL, where development started about a year ago and at ANL, where development is just getting underway, have shown that this approach to H^- production is clearly

superior (for accelerator applications, where beam size and emittance are important considerations) to the brute-force approach in which several amperes of positive hydrogen ions, a gas or vapor target for double electron attachment, and a magnetic separator are required to produce a monoenergetic 50 mA H^- ion beam.

Problems which cause existing Penning surface plasma sources to fall short of the performance required for IPNS and SNS have been identified. The most serious appears to be the problem of extending the duty factor. A Russian source has exceeded the current and pulse rate requirements for IPNS but falls short of the required pulse length. Scaling down in current and pulse rate and up in pulse length will result in an average arc power $\sim 50\%$ greater in the IPNS source than in the existing Russian source. More efficient cooling will have to be provided to dissipate this additional power to the source cathode and anode. Pumping requirements for the IPNS source will be formidable unless significant improvements in gas efficiency are achieved during the course of development of the Penning source.

The immediate objective of the H^- source program at Argonne is to produce an operational Penning source for direct H^- injection into the ZGS and Booster II as quickly as possible.

The beam intensities and duty cycles required for these applications were achieved during initial tests of the present source. During these tests, the arc and beam currents were quite noisy and gas consumption was excessively high. Efforts to eliminate these problems are underway. At Rutherford, Penning - discharge studies will be conducted while a complete source assembly and a test stand are being built, over the next six months or so.

Results of studies and development efforts at one laboratory will be communicated to the other on a quarterly or more frequent basis. More active collaboration will occur as occasions arise where studies or experiments initiated at one laboratory may be more expeditiously or conveniently conducted at the other laboratory.

A.2 Beam Loss in the Injector Linac

1. The high duty cycle, high mean current, performance required of the SNS and IPNS injector linacs demands that consideration be given to the problems of beam loss in these machines. A comparison can be made with the maximum design performance of existing machines:

	<u>MEV</u>	<u>mA</u>	<u>μs</u>	<u>Hz</u>	<u>μ A(mean)</u>
FNAL Injector	200	100	100	15	150
BNL Injector	200	100	200	30	600
LAMPF	800	17	500	120	1000
RL (SNS)	70	20	500	53	530
ANL (IPNS)	100	15	740	60	666

2. Heating due to beam loss

(i) Untrapped preinjector beam. Some 50% of the preinjector beam will be untrapped and create a heat load to the drift tubes. Assuming a 500 μ A loss at a mean energy of 1 MeV, gives a 500 W heat load, which can be compared with the combined rf and magnet heat load in the first drift-tube of the RL linac of 130 W. It can be assumed that the beam loss will be distributed over a number of drift-tubes. Local heating of the drift-tube bores is unlikely to cause a problem.

(ii) Beam stop for accelerated beam. The 35 kW of beam power from the RL linac would require a carefully designed and expensive beam stop if it were proposed to dump this beam during linac commissioning. It might be acceptable to restrict the average beam current during commissioning.

3. Shielding. Beam losses in the BNL and FNAL linacs were estimated during their design at approximately 0.1% above 10 MeV. Biological shielding should probably be designed for a 1% beam loss, for which a concrete shield wall of 6 ft thickness

at 70 MeV should be adequate.

4. Activation. Continuous beam loss to give 100 mR/hr. at 1 m, after 1 hr. cooling, at 50 MeV, in copper, is of the order:

Loss at a point, 0.25 μ A

Uniform loss over 30 m, 2.0 μ A

Clearly, for hand-on maintenance of the linac, these losses are upper limits and should probably be reduced by at least an order of magnitude.

5. Radiation damage. Assuming 0.1 neutrons produced per proton lost at 70 MeV, and of the order 1.4×10^{-8} Rads per n/cm², then for a uniform loss of 5 μ A of beam current over the 150 ft length of the RL linac the dose at the 70 MeV end is of the order 10^7 Rad/year at 10 cm. This should be acceptable for most linac components and materials. However, all semi-conductor electronics must be located outside the shielding wall.
6. Linac radial acceptance. Present information suggests that H⁻ ion beams can be produced with emittance values no worse than these emittances should be well within the linac acceptance and with something to spare. The RL linac will operate in the FFDD focusing mode giving a normalised acceptance of 10π mm. mr.
7. Longitudinal acceptance. Beam loss will be sensitive to any instability in phase between tanks. Instabilities of up to 17° have been observed in the RL linac, probably due to electron reactive loading. Fast phase control will be introduced for this linac. Electron loading effects are unlikely to be a problem in a modern linac with a clean vacuum system.

Note: There was no spokesman from either LAMPF or ANL on the topic of linacs.

A.3 Beam Loss and Activation in the Synchrotron

This discussion was attended by the entire study group. Graham Rees presented the thinking of the SNS group on this subject.

Philosophy

The enormous quantity of protons to be handled in both machines dictate a new operational philosophy from that previously used at either Nimrod or the ZGS. The HIS proposes to accelerate 2000 times the protons handled by the ZGS. The SNS group plan to set a hard limit on the beam loss at 2×10^{11} eight hundred MeV protons per cycle during 50 Hz operation. During tune-up and troubleshooting, this limit would be adjusted for energy and repetition rate to be an equivalent loss rate. This pointed out the necessity of making operational mode changes simple and diagnostic procedures clearly defined so that on shift operators could handle most of them without staff help after stable operation is achieved.

Injection Losses

Uncaptured or conditionally stable captured 70 MeV (100 MeV) beam will represent from 30 to 50% of the injected particles. It is important to dispose of these particles in a controlled way. SNS suggested kicking the unbunched beam into catching targets very early in the acceleration cycle. HIS ideas included injecting directly into the rf bucket by chopping in the linac or more exotic, an intermediate storage ring. Since chopping in the linac would introduce tails on the bunches, it was agreed that kicking in the circular machine would likely be better. Even better, it was agreed, was a very efficient capture process. It would seem that work on the capture process and a conservative injection scheme ought to take first priority.

SNS plans a vacuum system capable of producing 3×10^{-7} Torr vacuum to minimize vacuum scattering. Experience in the ZGS indicates that vacuums at least that good will be required to minimize proton-residual gas instabilities.

Acceleration Losses

SNS plans a system of vertical deflecting foils which would drive vertically scattered protons into catching targets. These targets would need to be water-cooled and the water could be used in a way to moderate the resulting neutrons.

Radially lost beam is harder to collect, but SNS plans an outer edge collecting system much like the vertical systems just mentioned. They noted the importance of an orbit trimming system to maximize the available orbit.

These collecting targets must be long to be effective, therefore, long straight sections are desirable in this type machine.

Extraction Losses

It was felt that a conservative philosophy was important here, too. This can best be done by designing apertures and fast kicks at least twice as great as that required by the theoretical beam size.

Remote Repairability

Neither group had come to grips with this question as yet, but quick magnet disconnect schemes in use at CERN were briefly discussed.

A.4 Magnets and Vacuum Chambers

The ring magnets for the high intensity synchrotrons discussed have several special requirements which they must satisfy. These are 1) 60 Hz operation, 2) operation in high radiation fields, 3) incorporation of an rf shield between the useful beam volume and the inside of the magnet gaps, and 4) good vacuum in the useful volume of the magnet gaps.

The 60 Hz operation demands that eddy currents in the magnet structure be minimized for reasons of their causing errors in the gap fields and their producing excessive power losses. The cores for the magnets will be laminated. The questions of concern for a laminated core are:

- 1) What are the core losses and how are they affected by the way in which the core is tied together?
- 2) What are the mechanical and vacuum properties of a laminated core with an externally attached vacuum shell?

The present design for IPNS is an unimpregnated, laminated core. The RL core will probably be bonded with epoxy resin, particularly since the dipoles are curved. ANL will be constructing a test core to look at the above questions in a dry core. The laminations used and basic core design are those of Booster II. RL has done some measurements of the vacuum properties of a stack of disks. Their results showed that a laminated core inside a vacuum system will require large pumping capacities to reach reasonable pressures. They expect that cryogenic pumping would also be necessary in the magnet gaps.

The need to operate in high radiation fields makes the core described above (unimpregnated) desirable. If the core were impregnated with epoxy and located inside the vacuum system, a large gas load in the vacuum space would be generated by beam losses striking the epoxy. The current coil designs of IPNS and SNS are different. SNS is severely limited by their power supply; they have to build a coil for operation at around 14 kV. To meet this requirement they must use an epoxy-based system. They feel that this will be acceptable if sufficient shielding is provided and the losses are kept down.

ANL is investigating MI conductor for their HIS coils. This conductor presents several problems. One is the induced voltage in the outside shield conductors. These voltages are the same as those on the conductor itself. To eliminate this problem, ANL now is considering the insertion of insulating gaps in the shield conductor. This gap must be sealed, however, to prevent loss and/or contamination of the insulation.

The second problem is the eddy currents in the shield conductor. ANL is in the process of developing codes to calculate these currents and their effect on the fields in the magnet gaps and the effects of the added power dissipation in the coils. ANL will also be able to test an MI coil in their test core and empirically determine some of the aspects of MI coils.

The ANL coils are now designed to have a voltage drop of about 1900 V maximum. This is roughly the potential to ground during operation for a power supply feeding the ring magnets at 16 points. If a fault occurs, one might expect higher voltages and probable breakdown of the insulation. The magnesium oxide insulation does not seem to be irreversibly damaged by this and, therefore, no serious problem is anticipated.

The rf shield proposed at this time by ANL is a radially segmented conducting cylinder which is electrically tied together along one side. The present RL design incorporates conducting strips of 2 mm thick stainless steel running along the inside surfaces of the vacuum chambers.

The last area of discussion was the method for providing the vacuums of 1×10^{-6} to 1×10^{-7} Torr required in the beam volume. RL now is proposing to build ceramic chambers made from sections about 10" long and joined together by a glazing process at about 1100°C. This chamber is designed so that it does not touch the pole surfaces, thereby eliminating vibration problems from the rapid cycling magnets. RL is running some tests now to define any problem areas related to radiation damage and to the effects of beam losses and thermal cycling.

The present ANL design uses the magnet core and outer vacuum jacket to provide a rough vacuum around the coils and inside the magnet gaps. The test core will help to evaluate the attainable pressures for this type of design. Hard vacuum chambers will then be located inside the magnet gaps. The detail of this chamber have not been developed yet, and will depend heavily on the results of the

test magnet work.

There is an alternate core design being considered at ANL by M. Foss. This involves the accelerator bending magnets and the chokes needed for the power supply to be incorporated in a single magnet structure. This magnet-choke contains a dc core (solid steel) and an ac core (laminated steel), and a dc coil (could be easily radiation hardened) and an ac coil (is relatively small). This magnet-choke appears to have a cost advantage of about 6% over a discrete geometry.

SUMMARY

The most difficult problems at this time are related to the required vacuums and the need for radiation hardened magnets. RL is involved now in R & D on a ceramic vacuum chamber. ANL is now doing R & D on aspects concerned with radiation hardened coils and cores which must operate in a 60 Hz system. The results of this work will, hopefully, allow us to proceed to more realistic designs for the ring magnets at both laboratories.

Collaboration

It was agreed to exchange information. At present, no areas are identified where specific help is required, but R & D work being done at both labs is of mutual interest and the results will be exchanged.

A.5 Summary of Discussion on Power Supplies

Present: Messrs. Roger Bennett and Barry Ward of Rutherford Laboratory and Charles Potts and Walter Praeg of ANL.

1. Ring Magnet Power Supply

Barry Ward described briefly the NINA 50 Hz power supply which is available for use at the Rutherford Laboratory for their 800 MeV proton synchrotron. The ac excitation of the resonant magnet network was provided for NINA by a pulse circuit, supplying a current pulse on the choke primary winding during the rising portion of the magnet current.

The current in NINA was stable within $\pm 0.01\%$. For the new synchrotron, a 395 A sinewave current is superimposed on a 660 A dc current. Both current components must be regulated within 0.01% and this will give a variation of injection field of about 0.5 G. The injection field is 1760 G, the peak field 7 kG. The losses are approximately 1 MW for dc and 1 MW for ac.

The objections to a pulsed supply are field perturbations and resonances excited by the pulse. Rutherford is now looking into continuous ac excitation by various means and including the possible use of a motor alternator set.

The question of phase-lock to the mains, of detuning an account of mains frequency changes and temperature were discussed.

W. Praeg mentioned that Argonne made a brief feasibility study for an IPNS-RMPS in 1975 to obtain cost estimates. Engineering design is anticipated to start in about a year.

With the success of the Booster II RMPS, where a 2300 A dc current is modulated by a 1853 A 30 Hz current by phase control of a 24-phase dc power supply, it is planned to use a similar but 36 or 48-phase system to generate the IPNS magnet current. The Booster II power supply and its phase control circuits were then discussed in more detail.

2. Injection Bump and Ejection Septum Magnet Power Supplies

Papers describing these pulsed power supplies were briefly mentioned. Copies of these papers were given to Messrs. Bennett and Ward, together with papers describing the transient protection of the ZGS-RMPS and ripple filter design.

3. Collaboration

It was agreed to exchange information. No areas where specific help would be useful to the participants were identified at this time.

A.6 Stripper

ANL presented observations on its experience with strippers to date. Paralene

foils have, in early tests, shown life-times of $\sim 10^{18} - 10^{19}$ p/cm² at 50 MeV. Actual foil lifetimes in BST-II have been \ll less, except for the present foil in use which has worked for over a week at various operating conditions. No clear reason can be given for its longevity, except that it coincides with the first period of operation in which beam is extracted. Beam is also carried "over-the-top" of the B-field so that non-extracted beam is now dropped radially outward. Whether or not the non-extracted beam has been the culprit is not clear.

The use of other materials was also brought up. ANL is having carbon foils ($\sim 50 \mu$ g/cm²) and silver foils (0.15 μ m thick) prepared for testing in BST-II. Results should be available within the month.

Since the use of paralene foils has some problems of using proprietary materials, it may be advisable that ANL provide paralene for early test.

A.7 Injection and Capture

Both HIS and SNS plan to use stripping of H^- ions to produce a large circulating current of protons for acceleration in the synchrotron. In both proposals the stripper is located near the inside aperture limit and bumper magnets are used to create synchrotron orbits near the stripper. These bumper magnets are turned off after injection so that the stripper is hidden from the accelerated protons.

SNS plans to inject the H^- from inside the ring, using the field of one of the bumper magnets to bend the beam to the correct injection angle. Care has been taken to locate the stripper at a favorable location in the lattice so that manipulation of the H^- beam during injection is not required. Due to difficulties of achieving good matching conditions for the external beam the energy spread of the beam must be limited. Therefore SNS plans to use smaller accelerating bucket sizes and to capture about 50% of the injected beam. Care will be taken to localize the lost beam into a special dump area.

Injection for the HIS proposal is very similar to the H^- injection method already used in Booster I and II. The H^- beam is injected from the outside and bent outward in a regular ring magnet to be headed in the direction of an inside closed orbit located near the stripper. Pulsed bumper magnets will be used to create these orbits and control their outward rate of movement away from stripper. Pulsed steering magnets in the H^- injection line will be used to keep the injected particles headed in the most favorable direction. The whole scheme is designed to create a nearly uniform transverse density to minimize space charge effects. A small energy ramp of the H^- beam will also be used for the same reason. The HIS accelerating buckets are large enough to contain a large energy spread. Adiabatic capture will be used in an effort to capture more than 70% of the injected beam. Localized beam dumps for absorbing the uncaptured beam will also be considered.

A.8 RF Systems

The IPNS and SNS RF System proposals were reviewed. SNS plans a 2 or 3 gap cavity with the gaps driven in parallel by conventional power amplifiers similar to the FNAL design. Beam loading would be controlled with a feedback scheme similar to that employed by the CERN ISR. The IPNS plans call for a single gap cavity driven by a low output impedance cathode follower type amplifier. The cavities would be resonated near the center of the frequency range and not be required to track.

The SNS frequency range is somewhat higher than IPNS but ferrite data, cavity/power amplifier designs, and low level rf systems are all likely areas for collaboration. In addition the Argonne Booster II accelerator has the capability of injecting with rf on but with the cavities out of phase. Since this is the injection mode planned for SNS some experience can be gained from Booster II experiments.

A.9 Extraction

The proposed extraction systems for the SNS and HIS accelerators are similar in a general sense. Both systems will utilize a bumped orbit to position the beam

optimally for extraction using fast kicker magnets and a septum magnet. However, for the SNS the beam is to be removed vertically whereas for the HIS radial extraction is proposed. The dispersive properties of the beam handling after extraction impose some additional complications for the SNS scheme. The kick angle for the SNS extraction scheme is about half that necessary for the HIS extraction although the apertures necessary for high intensity beams force the kicker designs to present some degree of difficulty in engineering and operation.

Critical review and discussion of the proposed methods has already contributed to the spirit of collaboration. The suggestion was made that the HIS scheme should examine the dispersive properties of the bumped orbit and consider also the possibility of vertical extraction. Concern was also expressed as to the consequences of back voltages on the thyratrons for the power supply circuits proposed for the SNS kickers.

SNS plans to build a prototype supply for the kicker magnets to test their circuit design. Results of investigations along these lines as well as experience at Argonne with the Booster II kicker magnet operation will provide information as input to both efforts.

B. Targets, Moderators, Calculations, Codes, Instruments

Participants

J. Ball	Argonne National Laboratory
A. Carne	Rutherford Laboratory
J. M. Carpenter	Argonne National Laboratory
R. K. Crawford	Argonne National Laboratory
B. Johnson	ARACOR
R. Kleb	Argonne National Laboratory
B. A. Loomis	Argonne National Laboratory

R. Prael

Argonne National Laboratory

G. J. Russell

Los Alamos Scientific Laboratory

T. G. Worlton

Argonne National Laboratory

B.1 Target System, Neutron Production, and Related Calculations

The agenda for these workshop discussions consisted of:

Target materials

Energy deposition

Target geometry

Irradiation damage

Gas production

Fabrication

Neutron production

Activation of target and coolant

Handling of radioactive target

Coolants

Lifetime of target

Prototype testing

Comparision of Rutherford, LASL, and ANL designs

Benchmark calculations and experimental testing

The above items were discussed in varying degrees of detail by presentation of the different designs envisioned by Rutherford, LASL, and ANL. The design parameters are summarized in Table 1.

	RUTHERFORD	ANL FNS-1 (NEUTRON SCATTERING)	ANL FNS-1 (RADIATION EFFECTS)	LASL
TARGET MATERIAL	SPRINGFIELDS U	U- 7-10 w/o Mo	TA OR W	TA
TARGET CLADDING	ZIRCALOY-2 (0.25 MM)	ZIRCALOY-2 (0.25 MM)	NONE	NONE
MAX. TARGET TEMPERATURE, °C	600	600	1000	300
TARGET COOLANT	WATER	NAK	NAK	WATER
TARGET GEOMETRY	STACKED DISCS	STACKED DISCS	ROD	ROD
TARGET ELEMENT DIMENSION	9-10 CM SQUARE .6-1.2 CM THICK	10 CM DIA, 1.0 CM, THICK } DISK	10 CM	2.5 CM DIA.
LENGTH OF TARGET (CM)	26	23	22	15
COOLANT CHANNEL (MM)	2	1	--	--
PROTON BEAM DIAMETER (CM)	6	7	7	1
PROTON INTENSITY (P/PULSE)	3×10^{13}	5×10^{13}	5×10^{13}	5×10^{11}
PULSE FREQUENCY (H _Z)	53	60	60	120
TARGET HEATING	420 KW	490 KW	200 KW	230 KW
BEAM INTENSITY DISTRIBUTION	PARABOLIC	GAUSSIAN	GAUSSIAN	GAUSSIAN
ASSUMED FOR CALCULATIONS				

The Rutherford experience on roll-bonding of zircaloy-2 to uranium shows good results for 0.6 cm thick uranium but much poorer results on increasing uranium thickness to 1.2 cm thickness. Diffusion bonding will be attempted for the future fabrications.

The Alsmiller (ORNL) calculations show the following dependence of neutron production/incident proton on target diameter for 800 MeV protons with gaussian distribution (FWHM = 3 cm). The target length is 34 cm. The data were obtained on a homogenized target of disks each with a thickness of U = 1 cm, NaK = 0.1 cm. Na = 0.0127 cm, and stainless steel = 0.0254 cm.

<u>Target diameter</u>	<u>Neutrons/protons</u>
6 cm	20.1
8 cm	21.9
10 cm	24.6
12 cm	25.5

$\sim 10\%$ of neutrons backstream and $\sim 0.3\%$ of neutrons exit the 34 cm plane.

The lifetime of the target may be determined in part by the magnitude of cyclic stresses developed due to proton beam energy deposition.

The ARACOR results (Table 2 and 3) on the generation of tensile and compressive stresses suggest that a pulsed energy deposition (10^8 cycles) of 1.9 KW/cm^3 in a U disk at 600°C is likely to exceed the endurance strength. A U-10% Mo disk has a marginal chance of survival. Ta or W disks have an adequate margin of safety against the cyclic stresses whereas the rods (~ 20 cm length) are likely to fail.

The NaK coolant (Table 4) will have an activity of ~ 60 Curies on shutdown after a 90 day operation. Approximately 10 days of activity decay will be required to allow manageable safe handling. Direct activation of water give yields of ~ 0.1

TABLE 2

PEAK TENSILE STRESS GENERATED IN PROTON-TARGET CONFIGURATIONS
AT TWO SINGLE-PULSE POWER DEPOSITIONS

ABSORBER MATERIAL	CONFIGURATION	INITIAL COMPRESSIVE STRESS (KBAR) *	PEAK TENSILE STRESS (KBAR) ABSORBER AT 600°C	
			2.8 kW/cm ³	1.9 kW/cm ³
URANIUM	UNCLAD DISK	0.88	0.82	0.55 EST.
URANIUM	STAINLESS STEEL CLAD DISK	0.88	0.75	0.50 EST.
URANIUM	ZIRCALOY-2 CLAD DISK	0.88	0.76	0.52 EST.
URANIUM	UNCLAD CYLINDRICAL ROD	0.88	2.5	1.7 EST.
TUNGSTEN	UNCLAD CYLINDRICAL ROD	0.72	3.7	2.5 EST.
TUNGSTEN	UNCLAD DISK	0.72	0.7 EST.	0.47 EST.
TANTALUM	UNCLAD CYLINDRICAL ROD	0.69	3.3	2.2 EST.

* AT 2.8 kW/cm³

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TABLE 3

MATERIALS PROPERTIES

ESTIMATED LOWER-LIMIT (STATIC) MATERIAL STRENGTHS OF URANIUM, TUNGSTEN, AND TANTALUM WITH AND WITHOUT IRRADIATION DAMAGE

ABSORBER MATERIAL	TENSILE STRENGTH (KBAR)			ENDURANCE STRENGTH (KBAR, 10^8 CYCLES)			
	<u>24°C</u>	<u>600°C</u>	<u>600°C W/NEUTRON DAMAGE</u>	<u>24°C</u>	<u>600°C</u>	<u>400°C W/NEUTRON DAMAGE</u>	<u>600°C W/NEUTRON DAMAGE</u>
PURE URANIUM	3.8-13	0.38-1.3	0.18-0.65	1.2-4.3	0.12-0.43	0.013-0.46	0.06-0.21
URANIUM (10% Mo)	3.8-13	1.0-3.5	0.5-1.7 ¹	1.2-4.3	0.3-1.1	0.33-1.1	0.15-0.5
TUNGSTEN (SWAGED ROD)	3.4-14	1.4-6	1.1-4.7 ²	1.1-4.6	0.46-2.0	0.56-2.36	0.36-1.5
TANTALUM	2.5-5	1.9-3.7	1.9-3.7 ²	0.83-1.6	0.63-1.2	0.72-1.33	0.63-1.2

¹EXPOSURE WAS 10^{19} TO 10^{20} NVT. IRRADIATION DATA WAS GIVEN AT ROOM TEMPERATURE

²EXPOSURE WAS 1×10^{19} NVT SLOW NEUTRONS AND 5×10^{19} NVT FAST NEUTRONS. IRRADIATION DATA WAS GIVEN AT ROOM TEMPERATURE.

TABLE 4

CLADDING EFFECT ON COOLANT CONTAMINATION

COOLANT CONTAMINATION (TOTAL CURIES)

TIME AFTER SHUT-DOWN FROM (DAYS)	SPALLATION ^A PRODUCTS	ACTIVATION ^B OF COOLANT	FISSION ^C FRAGMENTS	TOTAL WITH CLADDING	TOTAL WITHOUT CLADDING
0	350 ^D (365)	57 (57)	340 (360)	417 (425)	750 (780)
1	60 (95)	15 (15)	135 (160)	75 (120)	210 (280)
10	53 (79)	(10 ⁻³) (0)	35 (74)	53 (79)	88 (150)

^AFROM ASSUMED DISTRIBUTION^BNA 24 AND K 42^CESTIMATED LEAKAGE INTO COOLANT WITHOUT CLADDING^D_{XXX} - FROM 90-DAY OPERATION

(XXX) - FROM 1-YEAR OPERATION

Curie of tritium and 1 Curie of ^7Be per day.

The Rutherford calculations indicate a 13°C thermal cycle per pulse at the target for a 600°C maximum temperature.

The lifetime of the target will also be determined by the dimensional changes caused by the accumulation of helium, krypton and xenon gas in bubbles. The gas filled bubbles may cause a loss of adequate cooling and/or rupture of target cladding.

The Rutherford calculations indicate for Springfields U a volume change of 0.65%/0.1% burnup (ratio of atoms fissioned/total U atoms). This value does not include the He contribution from the evaporation reactions. The 0.65% $\Delta v/v$ /0.1% burnup suggests ~ 10 -12% $\Delta v/v$ of U in 100 days of operation at 600°C (3×10^{13} protons/pulse). The ANL calculations suggest a swelling value at 600°C for Springfields U of 13% in 100 days for 5×10^{13} protons/pulse intensity. The corresponding swelling for U-10% Mo is 6.5% in 100 days. The ANL calculations consider the contribution of He, Kr, and Xe. The above calculations are based on Kr and Xe production data for thermal neutron fission. The Kr and Xe production is expected to be less for fast neutron fission.

The experimental determination of the effects of thermal cycling on the dimensional stability of the proposed target materials would be useful data to acquire. Cross-section data for production of He, Kr, and Xe are needed for a more accurate prediction of the volume changes that may be expected.

The expected lifetime of the various target materials according to ARACOR is shown in Table 5.

TABLE 5

TARGET DESIGN OPTIONS COMPARED

TARGET	MAX LEAKAGE ^D PER PROTON	NEUTRONS PER PROTON	LIFETIME ^A	F.O.M. ^B	FACTOR FOR ^C ANNUAL COST	COMMENTS
DISKS						
BASELINE (CLAD U-MO)	0.040	22.2	3 mo.	1		
UNCLAD U-MO	0.043	23.6	3 mo.	1.06		
CLAD U ^E	0.044	24	2 mo.	0.72		
UNCLAD U	0.047	25.5	1 mo.	0.38		
CLAD TH-U	0.029	20.5	4 mo.	1.23		30 WT PERCENT U; 20% INCREASE IN LENGTH RE- QUIRED FOR NEUTRON OUTPUT
UNCLAD TH-U	0.031	22	4 mo.	1.32		
STACKED U RODS	0.048	26	?	—		REJECTED BECAUSE OF STRESS FAILURE ²⁴
MELTABLE U	0.047	25.5	1 YEAR	4.6		EXTERNALLY COOLABLE BY HE OR NAK;
MELTABLE ^F U-MN	0.044	24	1.2 YEAR	5.2		LIFETIME LIMITED BY EXTERNAL CONTAINMENT
PURE TUNG- STEN DISK	0.026	14	1 YEAR	2.5		RANGE OF PROTONS IN W COMPARABLE TO THAT IN U

A ESTIMATED MAXIMUM

B FIGURE OF MERIT = (NEUTRONS PER PROTON) X LIFETIME

C DATA PENDING

D NEUTRONS/CM²-PROTON (AT AXIAL MAXIMUM)

E FROM ALSMILLER CALCULATIONS

F DENSITY ESTIMATED

B.2 Computer Codes and Calculations

The workshop discussion included a review of the Monte Carlo computational capabilities of the participating laboratories. At Rutherford Laboratory, a modified version of the ØRNL high energy nucleon transport code HETC is used for target calculations and is being interfaced with Ø5R to extend the target calculations below 20 MeV. The TIMØC code is used for reflector-moderator studies and may also be directly interfaced with HETC. At LASL, the HETC code or its predecessor, NMTC, are interfaced with the LASL code MCNG below 20 MeV; in the future, the improved code MCNP will be used. At ANL, a recent version of HETC is interfaced with the VIM code below 15 MeV; potentially, the MØRSE could also be used for the low energy calculations.

At the present time, it appears that none of the laboratories has a complete code system for directly calculating thermal neutron beam intensity from incident proton beam intensity. The Rutherford and LASL codes have time dependance but lack a true thermal scattering capability, while the ANL VIM code includes a full thermal treatment but lacks time dependence. The development of a thermal scattering capability for MCNP of LASL is contemplated; at ANL, the production version of VIM will be modified to include the time dependence and variance reduction techniques used in early VIM calculations of leakage spectra from spallation neutron sources.

It was the consensus of the workshop that the calculation of high energy fission product yields is essential for questions of hazards analysis and irradiated target disposal. The ability to provide such calculations has been implemented in the HETC codes at Rutherford Laboratory. A similar capability may be forthcoming is an improved version of HETC from ØRNL; however, over the short term, we will probably have to look to Rutherford for codes and/or calculations in this area.

The MUSTA experiments undertaken by Rutherford Laboratory provide an opportunity for benchmark calculations on thermal and epithermal neutron spectral shape, with

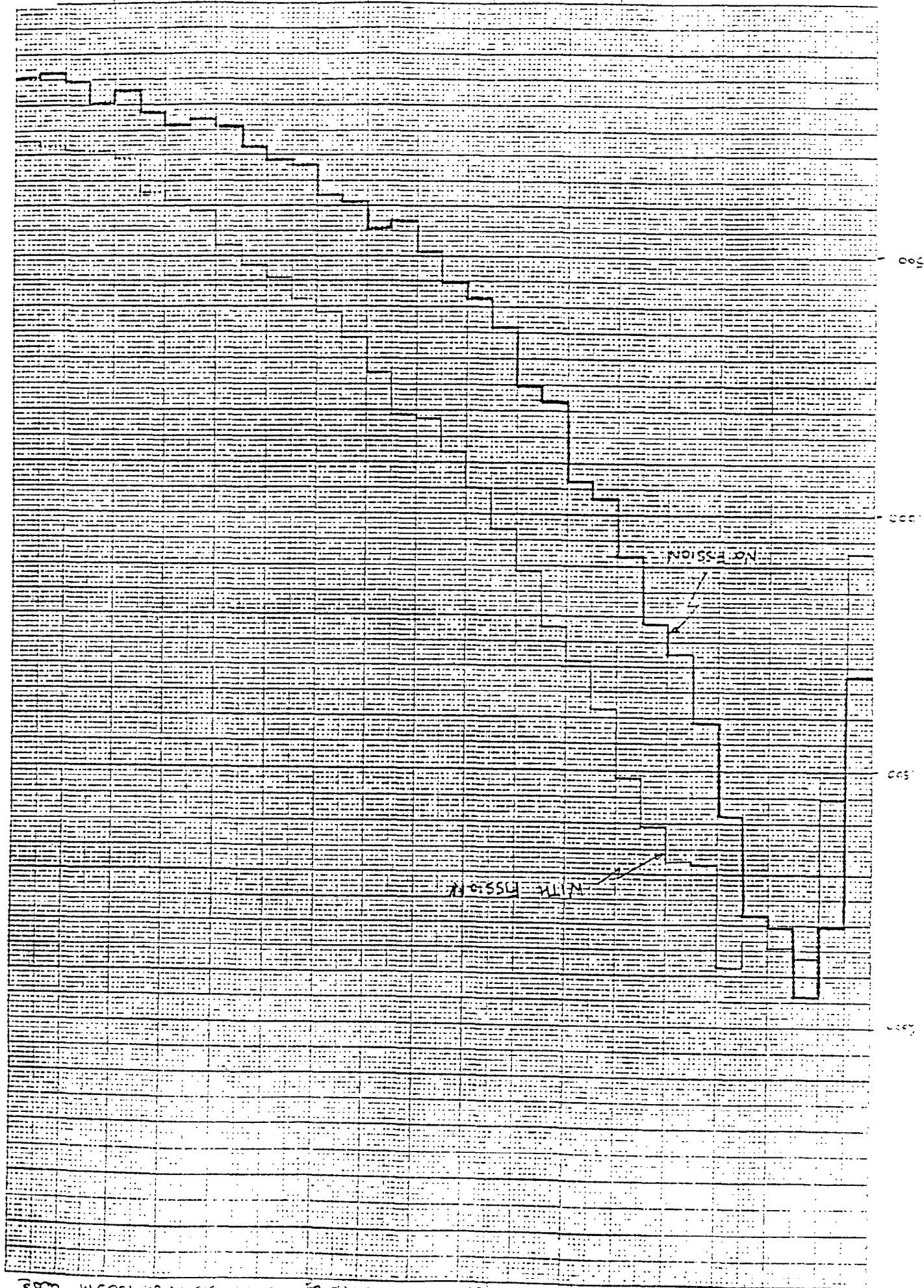
a possible extension to absolute intensity calculations. Undertaken primarily at 720 MeV, with some experiments at 800 MeV and 900 MeV, the MUSTA experiments provide data for H_2O moderator, H_2O , D_2O , and N_2 coolants, and graphite and Be reflectors. The final report, with analysis and benchmark specifications, is expected soon.

A benchmark for neutron production and energy deposition calculations will be provided by upcoming LASL experiments on a cylindrical Pb target. Further experiments on a 37 rod U cluster may be equally useful, but the desirability of a clean calculational benchmark for neutron production from fissionable material is so great that it is recommended that a cylindrical U target be included in the experiments if at all possible.

Included as an attachment are sample results obtained by Rutherford Laboratory for evaporation neutron spectrum (Fig 1) and residual masses after evaporation (Fig 2) using their modified HETC code to account for high energy fission. Results shown are for 800 MeV protons incident on a 1000 m^3 cube of ^{238}U , with a normalization of events per 1000 proton-induced cascades.

B.3 Neutron Scattering Instrumentation

The status of the ANL program of design and development of neutron scattering instruments for IPNS was briefly discussed. Prototype work is being carried out at the pulsed source prototype ZING-P' which started producing neutrons in November, 1977. Four instruments are nearly complete for operation at ZING-P' now. These are a High Intensity Powder Diffractometer which is also intended for studies of liquids and glasses, a High Resolution Powder Diffractometer (0.3% resolution), a Crystal Analyzer Spectrometer for inelastic spectroscopy at energy transfers up to 300 meV but with no momentum transfer resolution, and a Chopper Spectrometer for energy transfers up to about 500 meV. Two more ZING-P' instruments are in the construction

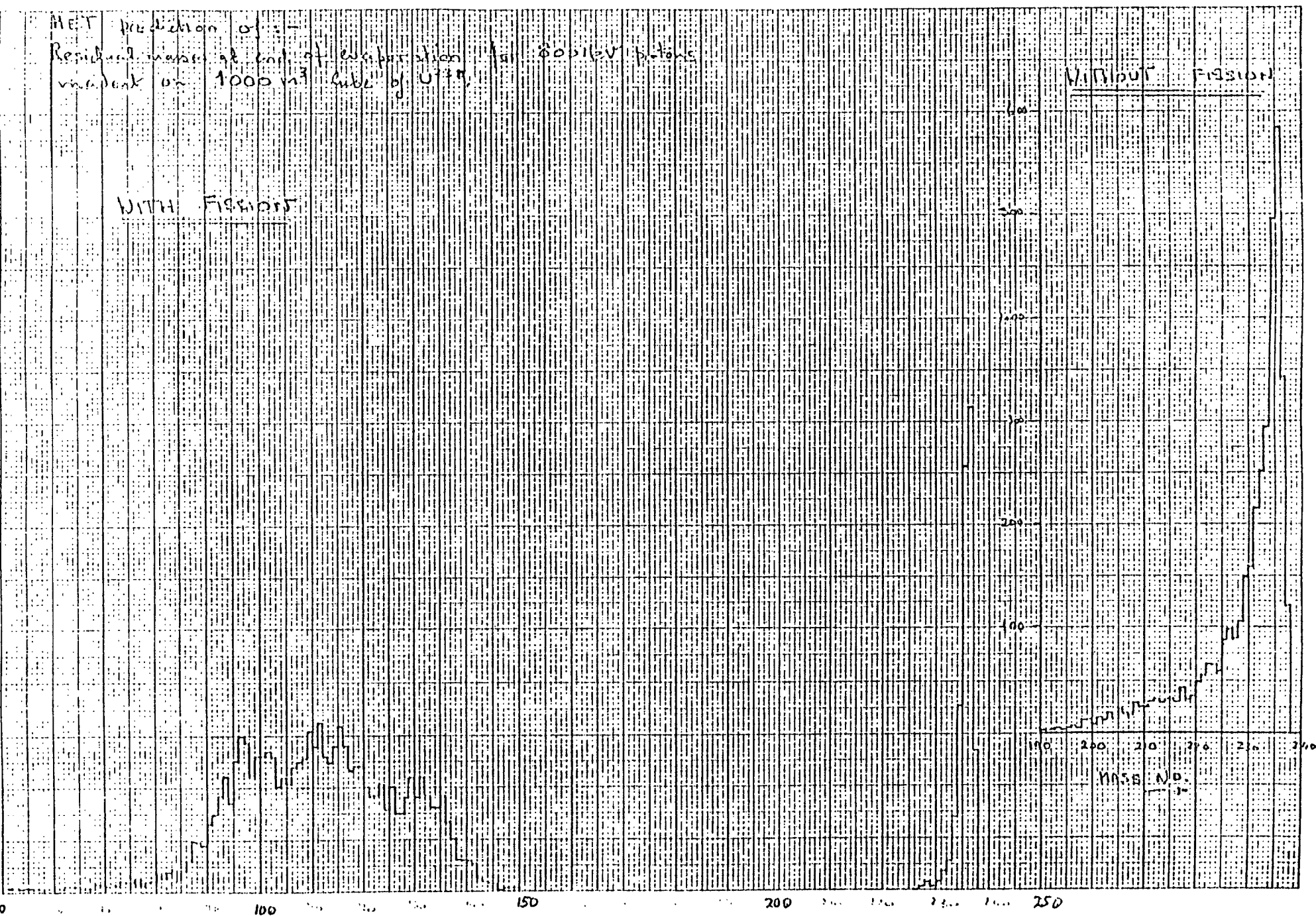


III
 EVALUATED SECTION OF THE 200 M² CUBE
 200 M² CUBE

NET prediction of:-
 Residual water at end of evaporation for 80016V plots
 incident on 1000 m² cube of UTR

WITH FISSION

WITHOUT FISSION



MASS NO.

Figure 2

stage. These are an Ultra-Cold Neutron Generator using a doppler shifting technique (ready in 1978), and a Single Crystal Diffractometer which will use a position sensitive multidetector $20 \times 20 \text{ cm}^2$ (40x40 resolution elements) which will be built at Oak Ridge by ANL personnel (instrument should be ready in 1979). A diffractometer with polarization analysis of the diffracted neutrons is being designed and construction will begin in 1978 (ready in 1979). Some tests of "white beam" polarizing techniques will be carried out in 1978 as well. Other instruments contemplated (but not necessarily planned) for operation at ZING-P' include a High Pressure Powder Diffractometer and an adaptation of the Chopper Spectrometer (TNTOS) currently in operation at CP-5 reactor. Development work on a resonance detector and on guide tubes is also planned.

In addition to this prototype development work, a number of conceptual designs for actual IPNS instruments have been considered and their performance has been evaluated. Instruments considered in such detail are listed in the Table 6. One general conclusion reached from these analyses is that chopper spectrometers are more versatile than are crystal analyzer spectrometers and are thus to be preferred for most inelastic scattering applications at IPNS. Highest priority for IPNS instrument construction will probably be given to a General Purpose Powder Diffractometer, a High Pressure Powder Diffractometer, and to chopper spectrometers similar to the designs CS1, CS2, and CS3. In addition some ZING-P' prototype instruments may be installed as part of the initial IPNS instrument complement. These include the High Intensity Powder Diffractometer (similar to design HID1), Single Crystal Diffractometer, and the Ultra Cold Neutron Generator.

TABLE 6

Summary of Instruments Considered in Detail, Including
Prototype Development Status Where Applicable

<u>Instrument</u>	<u>Examples of Scientific Area</u>	<u>Comments</u>
High Intensity Diffractometer (Design HID1)	Surface structures, absorbed and intercalated species. Transuranic compounds. High spatial resolution studies of glasses and molecular liquids.	$\Delta Q/Q \sim 0.01 - 0.03$ $0.2 < Q < 50 \text{ \AA}^{-1}$ An instrument very similar to HID1 is ready to operate at ZING-P'.
High Resolution Diffractometer (Design HRD1)	Medium-size crystal structure analysis with powders. Line broadening by anisotropic particle sizes, strains.	$\Delta Q/Q \sim 0.001$ $1.3 < Q < 12.6 \text{ \AA}^{-1}$ A similar instru- ment with Q/Q 0.003 is ready to operate at ZING-P'.
Single Crystal Diffractometer (Design SCD1)	Protein structures (position of H, H/D substitution, resonant nuclei). Weak satellite reflections in 1-D conductors at low temp.	Unit cells up to $\sim 100 \text{ \AA}$. A smaller scale prototype with a two-dimensional position-sensitive multidetector is scheduled for oper- ation at ZING-P' beginning in 1979.
Small Angle Diffractometer (Design SAD1)	Studies of macromolecules in solution. Structures of polymers. Studies of precipitation, void formation and other metallurgical problems.	$0.0001 < Q < 0.2 \text{ \AA}^{-1}$, $\Delta Q = 0.0001 - 0.001 \text{ \AA}$ Development will be based on development work for the Single Crystal Diffractometer
Medium Energy Chopper Spectrometer (Design CS1)	Higher harmonic modes in hydrides. Paramagnetic scattering from mixed-valence systems. Stoner excitations in ferromagnets. Spectroscopy of optically forbidden electronic transitions. Measurements of ground state momentum distributions.	$150 \text{ meV} < E < 1000 \text{ meV}$ $\Delta E/E \sim 0.01 - 0.10$ A prototype version is ready for operation at ZING-P'.

TABLE 6, Cont'd

<u>Instrument</u>	<u>Examples of Scientific Area</u>	<u>Comments</u>
Low Energy Chopper Spectrometer (Design CS2)	$S(Q, \omega)$ in amorphous solids, hydrides, dense gases, liquids. Dispersion of high-lying lattice modes. Metallurgical studies of elastic diffuse scattering. (clustering, short range order, interstitials, precipitates.)	$E < 150 \text{ meV}$ $\Delta E \sim 1 \text{ meV}$ Involves fairly minor modifications of an instrument now in use at the CP-5 reactor at ANL
Ultra High Resolution Chopper Spectrometer (Design CS3)	Diffusion in superionic conductors and other materials. Low-energy motions in plastic and liquid crystals, polymers, biomolecules. Tunnelling.	$E < 20 \text{ meV}$ $\Delta E = 10^{-6} - 10^{-4} \text{ eV}$
Constant- \vec{Q} Spectrometer (Design CAS1)	Excitations in single crystals. Some items listed for CS1 and CS2.	$E < 500 \text{ meV}$ $\Delta E/E \sim 0.03 - 0.10$ Constant vector Q scans. Could be adapted for polariza- tion analysis.
General Purpose Crystal Analyzer Spectrometer (Design CAS2)	Most items listed for CS1 and CS2.	$E < 500 \text{ meV}$ $\Delta E \sim 0.2 - 50 \text{ meV}$ Could be adapted for polarization analysis.
Energy Focussed Crystal Analyzer Spectrometer (Design CAS3)	Molecular vibrations in solids.	$E < 300 \text{ meV}$ $\Delta E \sim 2 - 10 \text{ meV}$ This instrument is ready to operate at ZING-P'.
Polarized Neutron Instrumentation	Dynamics of spin glasses, amorphous magnets. Separation of $S(Q, \omega)/S_{\text{inc}}(Q, \omega)$ in liquids, etc.	A prototype diffractometer with polarization analysis of the scattered neutrons with a crystal monochromator. polarizer is being designed for operation at ZING-P'.
Ultra Cold Neutron Generator	Basic measurements of the electric dipole moment, charge, and lifetime of the neutron. Studies of surface effects in "bottle".	10^6 n/pulse A prototype is being built for operation at ZING-P'.

INFORMATION EXCHANGE

To help facilitate information exchange among the participating laboratories it was requested that technical communications be routed through specific contact points in each laboratory, or at least that these contacts receive a copy of all technical communications. The contact persons for the different areas are listed below.

Please route pulsed neutron source information exchange to or through these persons.

	<u>IPNS (ANL)</u>	<u>SNS (RL)</u>	<u>WNR (LASL)</u>
Accelerator	J. D. Simpson (360)	Brian Boardman	R. Cooper (AT3)
Target	T. G. Worlton (330)	Brian Boardman	G. Russell (P9)
Instrumentation	R. K. Crawford (223)	Brian Boardman	T. Kitchens (P8)
Mailing Address:	Argonne National Lab.	Rutherford Lab.	Los Alamos Scientific Lab.
	Argonne, Illinois	Chilton, Didcot,	Los Alamos, New Mexico 87544
	60439, USA	OXON OX11 0QX	USA
		ENGLAND	

FUTURE MEETINGS

It was unanimously agreed that similar additional meetings with these or other topics emphasized would be most valuable. Tentative locations, times, and agenda for the next two meetings were proposed, with the stipulation that final details regarding the first of these two should be worked out as soon as possible. These tentative meeting plans are included below. Any suggestions or questions regarding these meetings should be directed to the proposed host institutions.

TENTATIVE AGENDA
for
2nd Workshop of the International Collaboration
on
Advanced Neutrons Sources

July 10-15, 1978
Rutherford Laboratory

NEUTRON SCATTERING INSTRUMENTATION AND
FACILITIES FOR OTHER APPLICATIONS

Source Specifications

- Moderators
- Data needs - Moderator & target
- Codes and calculations - Benchmark calculations
- Target designs

Experimental Program Needs

- Scattering Instrumentation Designs (specific)
- Data Acquisition System
 - Computers and interfaces
 - Software, firmware
 - Detectors
- Special Components
 - Guide tubes
 - Special environments
 - Polarization devices
- Other Instrumentation
 - Radiography
 - Thermal neutron irradiation
 - Nuclear cross sections
 - Nuclear chemistry
- Radiation Damage Facilities

Review of Accelerator Designs